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TEXTILE SERIES - REPORT NO. 51



# CORRELATION OF SIMULATED RAINFALL TESTS WITH LABORATORY PENETRATION TESTS





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M. I. LANDSBERG, ROGER KELLY, AND DOROTHY SINSKI



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## FOREWORD

During the recent war and post-war years the Quartermaster Corps has carried on an active research program leading to the development of improved water-resistant garments for Army personnel. As pointed out in Textile Series Report No. 25, "Areas of Quartermaster Research in Textiles," the problem of water resistance has been studied in this program under four major phases: (A) Principles of Fabric Construction, (B) Influence of Finishing and Aftertreatment, (C) Evaluation and Testing Techniques, and (D) Garment Design. It is evident that efforts to improve the water resistance of cloth and garment must be preceded by the development of valid testing techniques to permit a true evaluation of the effect of variations in material components and manufacturing procedures.

The first step in this development was the investigation of methods of producing simulated rainfall. This work led to the construction of a "rain room" at the Philadelphia Quartermaster Depot; later a "Rain court" was erected at the Quartermaster Board, Camp Lee, Virginia. The research leading to these unique testing instruments has been described fully in a report published in the Textile Research Journal in 1946.

Although these installations provided the most effective and accurate means of evaluating water resistance, they were soon found to be too clumsy, expensive and time-consuming to be used as screening agents. This was found to be particularly true as fabrics of greatly improved water resistance were developed, which required up to a hundred hours of testing under simulated rainfall before failure occurred. Therefore, it became necessary to establish a correlation between results obtained under simulated rainfall and those obtained by means of the more rapid and simpler laboratory techniques. The following report attempts to formulate such correlations using the rain room as a criterion. By establishing these relationships and illustrating their practical application the way is opened to a rapid and valid evaluation of the water-resistant qualities of textile fabrics.

Methods described herein have been used in the evaluation of improved textile structures developed under Part A of the water-resistance program, and in the near future it is planned to release a report covering this activity.

September 1949

S. J. KENNEDY
Research Director
for
Textiles, Clothing and Footwear

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ABSTRACT

A correlation has been established between the results of rain-room tests on garments and swatches and the results of the following laboratory tests: drop-penetration, du Pont rain test, Bundesmann, and hydrostatic pressure.

Two series of fabrics were used for this study. The first (Series I) included seven commercial and military type materials whose resistance to penetration varied from very poor to very good. The second (Series II) consisted of 25 experimental materials of excellent water resistance which had been produced with controlled variations in constructional factors such as yarn twist, size, and ply; texture and weight.

The relationship between the results of three of the laboratory tests and rain-room penetration time can most simply be represented by the general equation

$$\text{Log } Y = a + b \log X.$$

For the hydrostatic pressure test the relationship is expressed by

$$\text{Log } Y = a + bX.$$

Based on the analyses which have been performed it has been shown that the drop-penetration test is most suitable for predicting rain performance of a wide range of fabrics. The duPont rain test, although not as widely applicable as the drop penetration test, is most suitable for estimating the rain performance of either single- or double-layer fabrics possessing the water-resistance characteristics desired by manufacturers producing civilian-type rain coats. The Bundesmann test appears to be almost as satisfactory as the rain tester, but its limited use and range preclude its general acceptance. The hydrostatic-pressure test is not as suitable for predicting the rain performance of a wide range of fabrics because of its relative insensitivity to those characteristics which influence rain protection, such as thickness and density.

## I. INTRODUCTION

The need for a convenient and reliable method of determining the extent and durability of the rain protection afforded by clothing fabrics has long been apparent. Although many laboratory tests are now in existence which can be performed with facility, no relationship has yet been established between the length of time a garment will keep the wearer dry and laboratory tests of the fabric from which that garment was made.

Obviously, the most direct means of determining the ability of a fabric to resist penetration is by testing in actual rainfall. This procedure is not feasible, however, because it is impossible to ensure that rainfall will occur at the desired time of test or that it will continue at a uniform rate for a sufficient period of time to permit direct comparisons between fabrics. Furthermore, it is difficult to secure reliable test data under natural rain conditions because of the lack of control over such variables as wind velocity and air and water temperature.

The accurate reproduction of rain by artificial means which would provide the controls required for the establishment of a valid testing program was therefore undertaken by technologists of the Quartermaster Corps Research and Development Laboratories at Philadelphia.(1) As a result of this work, three nozzles were developed which were capable of producing rain at the rates of 0.1, 1.0 and 3.0 inches per hour, duplicating with considerable accuracy the three prime characteristics of natural rainfall: intensity, drop size, and drop velocity.

These devices provided a unique testing instrument which was accepted as the most suitable criterion for determining the water resistance of fabrics and garments and the efficacy of various repellent compounds. Two general methods of evaluation were used in the rain room. One was the testing of garments worn by human subjects and the other the testing of fabrics on specially designed holders. Although garment tests are desirable from the service standpoint, it has been found that the fabric holders can be used to furnish quantitative data of greater research value since by this method certain variables, such as the effect of seams and individual wearing characteristics of the human test subject, are eliminated.

The rain room was recognized as a valid testing device, but its operation was costly and time consuming, and required much personnel. The study described in this report was therefore undertaken in an effort to establish a correlation between rain-room results and data obtained by the much simpler and more economical laboratory tests. Such a correlation would make it possible to predict the rain-room behavior of a given sample on the basis of laboratory tests, and would thus eliminate the necessity for the rain room, except possible as a final check of the most desirable fabrics or fabric-repellent combinations. The study

involved the establishment of two separate correlations: first, between rain-room results using the two different methods of testing, viz., as garments worn on human test subjects and as swatches clamped on fabric holders; and second (provided a satisfactory relationship is found to exist in the first), between laboratory data and the results of rain-room tests using fabric holders.

Two series of fabrics in different ranges of water resistance were used for this correlation study. The first (Series I) included several commercial and military type fabrics whose resistance to penetration varied from very poor to very good. The second (Series II) consisted of 25 experimental materials of excellent water resistance which had been produced with controlled variations in constructional factors such as yarn twist, size, and ply; texture; and weight.

Although this study represents a relatively comprehensive correlation analysis between laboratory and rain-room tests, it should be emphasized that the number of fabrics in Series I (seven) is not sufficient to cover completely the wide range of water resistance represented. The 25 fabrics in Series II, on the other hand, all of which possess a high degree of water resistance, should be satisfactory in number of samples, although here a limitation is present in that only one weave (Oxford) was tested. These data, however, if properly used, should give some valuable indications as to the protection which will be afforded by garments made from fabrics tested in the laboratory.

## II. EXPERIMENTAL PROCEDURE

### Materials

Series I. The seven fabrics used in the first part of this study were civilian and Army type materials finished, dyed, and treated with the same durable water repellent compound. The physical properties of these fabrics are listed in Table I.

TABLE I

CONSTRUCTIONAL FACTORS OF FABRICS IN SERIES I

| Fabric Number | Weave | Weight (oz./sq.yd.) | Thickness (inches) | Texture Warp | Texture Filling | Yarn Number Warp | Yarn Number Filling |
|---|---|---|---|---|---|---|---|
| 1. | Poplin | 6.20 | .0156 | 107 | 54 | 40/2 | 15 |
| 2. | Sateen | 8.78 | .0228 | 112 | 70 | 36/2 | 22/2 |
| 3. | Oxford | 8.50 | .0191 | 132 | 46 | 36/2 | 13 |
| 4. | Poplin | 4.86 | .0126 | 109 | 63 | 48/2 | 24 |
| 5. | Poplin | 4.39 | .0142 | 117 | 42 | 33 | 15 |
| 6. | Twill | 5.21 | .0161 | 118 | 55 | 22 | 25 |
| 7. | Gabardine | 9.01 | .0287 | 133 | 75 | 28/2 | 21 |

Series II. The 25 fabrics used in the second part of this study were all experimental oxford weave fabrics ranging in weight from 6 to 25 oz./sq.yd. These fabrics were all finished alike and treated with an Army-approved durable water-repellent compound. The physical properties of these fabrics are listed in Table II.

TABLE II

CONSTRUCTIONAL FACTORS OF FABRICS IN SERIES II

| Fabric Number | Weight (oz./sq.yd.) | Thickness (inches) | Texture | | Yarn Number | |
|---|---|---|---|---|---|---|
| | | | Warp | Filling | Warp | Filling |
| 1 | 5.89 | .012 | 200 | 95 | 75.7/2 | 75.7/2 |
| 2 | 7.57 | .015 | 161 | 79 | 75.7/3 | 75.7/3 |
| 3 | 8.75 | .016 | 144 | 70 | 60.2/3 | 60.2/3 |
| 4 | 11.12 | .021 | 116 | 56 | 38.3/3 | 38.3/3 |
| 5 | 15.78 | .029 | 80 | 40 | 18.6/3 | 18.6/3 |
| 6 | 6.17 | .013 | 196 | 83 | 75.7/2 | 57.9/2 |
| 7 | 7.77 | .016 | 160 | 70 | 75.7/3 | 60.2/3 |
| 8 | 9.17 | .018 | 151 | 60 | 60.2/3 | 43.3/3 |
| 9 | 16.29 | .031 | 80 | 35 | 18.6/3 | 14.2/3 |
| 10 | 23.70 | .045 | 56 | 24 | 9.1/3 | 7.0/3 |
| 11 | 6.84 | .015 | 194 | 71 | 75.7/2 | 41.1/2 |
| 12 | 8.34 | .018 | 159 | 56 | 75.7/3 | 38.3/3 |
| 13 | 9.85 | .020 | 140 | 49 | 60.2/3 | 29.3/3 |
| 14 | 13.70 | .029 | 98 | 34 | 29.3/3 | 14.2/3 |
| 15 | 25.26 | .050 | 56 | 19 | 9.1/3 | 4.5/3 |
| 16 | 6.07 | .013 | 185 | 89 | 75.7/2 | 57.9/2 |
| 17 | 7.71 | .016 | 150 | 74 | 75.7/3 | 60.2/3 |
| 18 | 16.16 | .030 | 75 | 36 | 18.6/3 | 14.2/3 |
| 19 | 13.26 | .025 | 82 | 39 | 29.3/3 | 21.9/3 |
| 20 | 23.19 | .045 | 47 | 21 | 9.1/3 | 4.5/3 |
| 21 | 7.89 | .016 | 162 | 73 | 75.7/3 | 60.2/3 |
| 22 | 16.75 | .031 | 79 | 36 | 18.6/3 | 14.2/3 |
| 23 | 7.26 | .014 | 194 | 82 | 75.7/2 | 41.1/2 |
| 24 | 15.27 | .027 | 98 | 40 | 29.3/3 | 14.2/3 |
| 25 | 19.07 | .034 | 79 | 32 | 18.6/3 | 9.1/3 |

## Rain-Room Tests

Description of the rain-room has been previously given in an article by Landsberg and Moody [1].

(1) Garments. The fabrics in Series I were tested by Slowinske and Pope [2] in the form of single and double-layer garments worn by human subjects, following (with some modification) the procedure for rain-room evaluation developed by the Quartermaster Research and Development Laboratories at Philadelphia. Each man wore his own suit coat,

shirt, and undershirt under the raincoat. The raincoats were worn until serious penetration occurred or until a total wearing time of two hours had elapsed. Serious penetration was defined as (a) wetting of the suit coat over an area of approximately 50 square inches, or (b) absorption of the suit coat to the extent of 30 or more grams. One to four single or double-layer raincoats of each fabric in Series I were tested. No garment evaluations were made of the Series II fabrics.

(2) Fabric Swatches. In the evaluation of fabrics in the form of sample swatches, a special hemicylindrical metal holder approximately 14 inches in length and 18 inches in circumference was used. (See Figure 1.) The fabrics were placed on the holder and kept in position by a hinged clamp lined with sponge rubber. A uniform tension was maintained throughout the test by a one-pound metal weight. Underneath the test fabric was placed an 8.2-oz. twill material to absorb the moisture penetrating the specimen. This backing fabric was removed at specific time intervals and weighed. The increase in weight of the twill cloth was used as a measure of fabric penetration. When 20 grams of water had penetrated the fabric being tested it was considered to have failed and the time for this failure to occur was used as its "rain-room penetration time". All the fabrics in both series were evaluated in this manner.

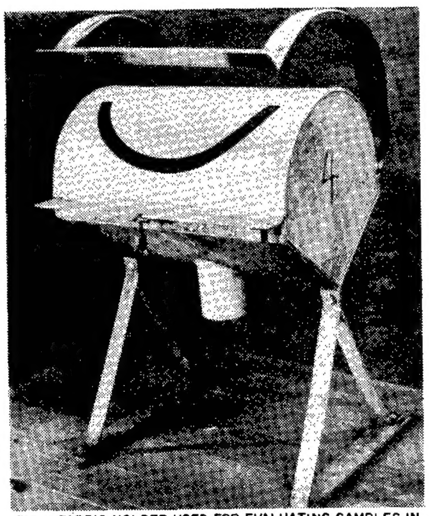

Fig. I - FABRIC HOLDER USED FOR EVALUATING SAMPLES IN THE RAIN ROOM

## Laboratory Tests

There are essentially two types of laboratory water-resistance tests: those which measure resistance to passage of water through a fabric, and those which measure resistance to wetting of the fabric itself. The present paper is limited to consideration of the first of these types, i.e., penetration tests, for two reasons. First, in the case of water-repellent clothing, the ultimate criterion from the standpoint of protection provided must be the amount of water penetrating the fabric, and not that which is merely absorbed, or which wets the outer surface. Second, the tests which measure the resistance of the fabric to wetting are, for the most part, not indicative of the inherent water resistance of its structure (as are the penetration tests), but of the efficacy of the water-repellent compound. Tests of this type, such as static and dynamic-absorption and several surface-repellency tests including spray-rating, contact-angle, and wetting-time determinations, were conducted, but since all the fabrics were treated in a uniform manner with the same repellent, the results fell within an exceedingly narrow range. Hence, their primary significance was to establish

the uniformity of the treatment and to indicate that any differences in penetration test results could be attributed primarily to differences in fabric structure.

The penetration tests described in this paper are as follows:

Drop Penetration

Suter Hydrostatic Pressure

duPont Rain Test

Bundesmann

In these tests (with the exception of the hydrostatic) the amount and pressure of the water are kept constant and the relationship between time and quantity of water penetrating the material is determined. The end point is expressed either in terms of the amount of water collected in a given period of time or the time necessary to collect a specific amount of water. The penetration tests differ from each other mainly in the amount and impact of water striking the fabric. In evaluating fabrics of good water resistance, differences are more clearly shown by tests in which the water strikes the sample with a relatively high velocity, while less severe conditions of test are required to show differences among the poorer fabrics.

The hydrostatic test differs from others in that (1) the pressure is increased at a controlled rate instead of being kept constant and (2) the fabric is maintained in constant contact with the water, producing in essence a static rather than dynamic type of test.

A brief description of the tests follows:

(1) <u>Drop-Penetration Test</u>. This test is described in Federal Specification CCC-T-191a (Supplement 8 October 1945).[3] The water which penetrates the fabric specimen passes through a crescent shaped slit in a fabric holder and is collected in a graduated cylinder. The drop-penetration value is reported as the time required to collect 10 ml. of water. All of the fabrics in Series I were evaluated in this manner. In the evaluation of the Series II fabrics a slight modification was made in the testing procedure because of their very high water resistance. The modification consisted of measuring the amount of water penetrating the test specimen during a three-hour period.

(2) <u>Hydrostatic-Pressure Test</u>. This test is described in Federal Specification CCC-T-191a (Supplement 8 October 1945).[3] A hydrostatic head is built up on the face of the fabric at the rate of one cm. per second. The height measured at the moment of penetration of three drops of water is taken as the hydrostatic-pressure value of the

fabric. The fabrics in both Series I and Series II were tested in the manner specified.

(3) duPont Rain Test. This test is described in a published article by Slowinske and Pope.(2) A horizontal water spray from a specified type of nozzle is directed against the test fabric placed at right angles to the spray, twelve inches from the nozzle. The water penetrating a specimen is measured by weighing a blotter placed behind the fabric. The rain-test value may be expressed either as the time required for the penetration of a specified weight of water, or as the weight of water penetrating within a specified time. Another alternative procedure consists of determining the time required for the penetration of the first drop of water as visually noted on the backing blotter. This test is applicable to a wide range of fabrics by virtue of the fact that the head of water can be varied from two to eight feet, thus increasing or decreasing the impact with which the water strikes the fabrics. For the fabrics in Series I, no modification of the test instrument was necessary. In the evaluation of the water-resistant fabrics in Series II, three modifications were made: (1) the distance of the nozzle from the fabric was decreased to six inches, (2) the design of the apparatus was changed in order to ensure that the streams of water hitting the specimens would be parallel, (4) and (3) the time of test was increased to 20 minutes.

(4) Bundesmann Test. This test is described in Tentative Textile Standard Nos. 7 and 8 of the British Textile Institute.(5) Fabric specimens are mounted over a series of revolving cups and subjected to a controlled spray. The underside of each fabric is rubbed by a rotating wiper arm inside the cup. The resistance of the specimen to penetration is indicated by the amount of water collected in the cups in a given time. This test is standard in European countries and in Canada, but has not been favorably accepted in this country because of the high cost of the apparatus required and the operational difficulties involved in the performance of the test. This test was used only in the evaluation of the fabrics in Series I.

## III. RESULTS AND DISCUSSION

### Rain-Room Correlations

Prior to the establishment of relationships between laboratory and rain-room test results, it was necessary to determine two correlations between different methods of testing in the rain room. The first of these concerned the extent of agreement which existed between tests of garments worn by human subjects and tests of sample swatches attached to fabric holders. The second was a correlation between results obtained on the fabric holders under a one-inch-per-hour rainfall and a three-inch-per-hour rain-fall.

The fabrics in Series I were tested in the rain room both as garments worn by human subjects and as test swatches mounted on fabric holders. Single-layer garments and fabric specimens were subjected to a one-inch-per-hour rainfall. For the single layers this intensity was found most suitable because it was sufficient to cause penetration through most of the materials in a relatively short time, yet did not produce such rapid failure that it was impossible to obtain an accurate ranking of the water resistance of the specimens and/or garments. In double layers the fabrics were tested only in swatch form mounted in fabric holders under a three-inch-per-hour rainfall. Although comparable double-layer garment data would have been desirable, it was not feasible to conduct a test with human subjects for a period longer than two hours, in which time only the two poorest double-layer fabrics showed signs of failure.

A comparison of penetration time obtained for garments on human subjects and fabric swatches on sample holders, as shown in Table III, indicates that under a one-inch-per-hour rainfall both of these methods rank the fabrics in the same order: 3, 2, 1, 4, 7, 6, 5.

TABLE III

RAIN-ROOM TEST RESULTS ON SERIES I FABRICS
(Time in minutes for penetration to occur)

| Fabric Number | Fabric | GARMENTS (1 In/Hr Rainfall) Single Layer | FABRIC SWATCHES (1 In/Hr Rainfall) Single Layer | FABRIC SWATCHES (3 In/Hr Rainfall) Double Layer |
|---|---|---|---|---|
| 3 | Oxford | 120 + | 1760.0 (a) | 1680.0 |
| 2 | Sateen | 100 | 625.0 (a) | 1530.0 |
| 1 | Poplin | 80 | 60.0 | 190.0 |
| 4 | Poplin | 60 | 37.5 | 60.0 |
| 7 | Gabardine | 25 | 30.0 | 52.5 |
| 6 | Twill | 20 | 22.5 | 26.3 |
| 5 | Poplin | 10 | 15.0 | 15.0 |

(a) Values estimated by extrapolation of curve showing rate of penetration after 6.5 hours.

Figure 2 indicates relatively good agreement between data obtained with fabric holders and with garments under a one-inch-per-hour rainfall when tested in single layers. The correlation coefficient expressing the degree of relationship between these results was 0.80 based on six of the seven fabrics. The oxford fabric No. 3 is not included because no failure was obtained in garment form. The coefficient of correlation is significant but not as high as would have been desired. However practical consideration precluded extended garment tests, making it necessary to accept results obtained on fabric holders as a basis for correlation with laboratory tests.

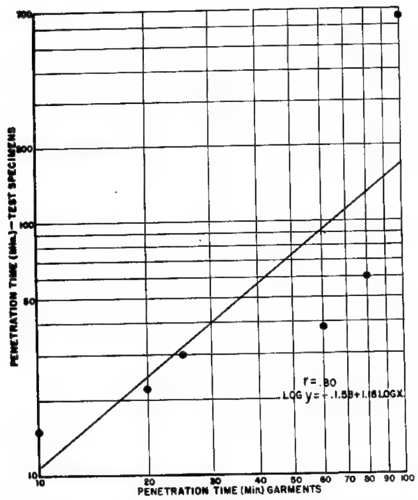

Fig.2-RELATIONSHIP BETWEEN AVERAGE PENETRATION TIME OF GARMENTS AND TEST SPECIMENS ON FABRIC HOLDERS EVALUATED IN THE RAINROOM (1"/Hr.RAINFALL) (SERIES I-SINGLE LAYER FABRICS & GARMENTS)

Since the correlation between tests of garments and fabric specimens on holders is considered satisfactory, it follows that fabric specimen data can be used to estimate the approximate performance under a one-inch-per-hour rain-fall of garments made from those fabrics. It also follows that the same data can be used for correlation purposes between rain-room and laboratory test results. It must be supplemented, however, with a correlation between results obtained under a one-inch-per-hour rainfall, since the latter intensity is required for practical testing of double-layer fabrics. As shown in Figure 3, a high correlation coefficient of 0.97 was found for this relationship. The good agreement between the penetration time for a single-layer fabric under a one-inch-per-hour rainfall and that for a double-layer under a three-inch-per-hour rainfall indicates that the increased intensity is compensated for by doubling the fabrics.

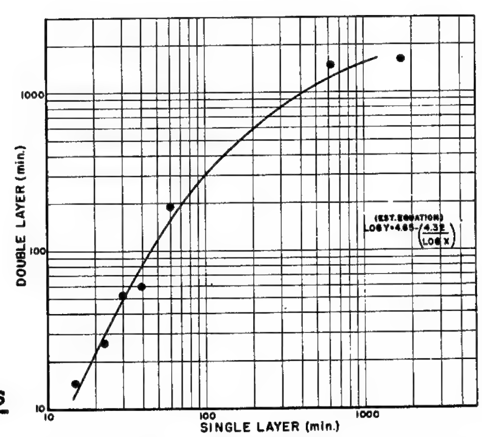

Fig.3-RELATIONSHIP BETWEEN RAINROOM PENETRATION TIME OF SINGLE LAYER (1"/HOUR RAINFALL) & DOUBLE LAYER (3"/HOUR RAINFALL) (SERIES I FABRICS)

<u>Correlation of Rain-Room and Laboratory Tests</u>

The rain-room evaluation of the fabrics and garments in Series I has been discussed. The 25 fabrics in Series II were evaluated on fabric holders under a three-inch-per-hour simulated rainfall. The fabrics in this series possessed such superior water resistance that it was not feasible to evaluate them under a one-inch-per-hour rainfall so as to permit direct comparisons with the fabrics in Series I. Even under a three-inch-per-hour rainfall some of the fabrics required nearly 100 hours of testing in order to obtain a break-through.

## TABLE IV

### COMPARISON OF RAIN-ROOM AND LABORATORY TEST RESULTS ON SERIES I FABRICS

| Fabric | Rain Room(a) (min.) | Hydro-static (cm.) | Drop Penetration (min./10 ml) | Bundesmann (gm./20 min.) | du Pont Rain Test: 2 Feet (gm/5 min) | du Pont Rain Test: 3 Feet (Sec.for initial penetration) | du Pont Rain Test: 3 Feet (Sec./4 gm.) | du Pont Rain Test: 8 Feet (Sec. for initial penetration) |
|---|---|---|---|---|---|---|---|---|
| **Single Fabrics** | | | | | | | | |
| 3. Oxford | 1760.0(b) | 63 | 54.0 | 0.0 | 0.0 | 930 | 144000+(c) | |
| 2. Sateen | 625.0(b) | 40 | 8.3 | 0.2 | 0.1 | 116 | 4100 (d) | |
| 1. Poplin | 60.0 | 36 | 3.8 | 1.8 | 0.2 | 20 | 1500 | |
| 4. Poplin | 37.5 | 34 | 3.8 | 3.9 | 2.2 | 8 | 120 | |
| 7. Gabardine | 30.0 | 26 | 1.4 | 20.0 | 11.7 | 1 | 14 | |
| 6. Twill | 22.5 | 26 | 0.8 | 59.0 | 12.7 | 1 | 4 | |
| 5. Poplin | 15.0 | 18 | 0.75 | 99.0 | 13.0 | 1 | 2 | |
| **Double Fabrics** | | | | | | | | |
| 3. Oxford | 1680.0 | 88 | 300+ | 0.0 | | | | 18000+ |
| 2. Sateen | 1530.0 | 52 | 91.0 | 0.0 | | | | ----- |
| 1. Poplin | 190.0 | 48 | 18.0 | 0.0 | | | | 1116.0 |
| 4. Poplin | 60.0 | 42 | 21.0 | 0.2 | | | | 38.0 |
| 7. Gabardine | 52.5 | 30 | 9.2 | 0.1 | | | | 35.0 |
| 6. Twill | 26.3 | 29 | 2.0 | 0.3 | | | | 7.0 |
| 5. Poplin | 15.0 | 21 | 1.3 | 3.0 | | | | 3.5 |

NOTES: (a) For single fabrics 1 in./hr; for double fabrics 3 in./hr.
(b) Values estimated by extrapolation of curve showing rate of penetration after 6.5 hrs.
(c) Value estimated by extrapolation; 0.1 gm. after 3600 sec.
(d) Value estimated by extrapolation; 3.5 gm. after 3600 sec.

The four laboratory penetration tests ranked the fabrics in Series I in single or double-layers nearly in the same order as did the fabric holders in the rain-room as shown in Table IV. Because of the large number of fabrics in Series II the establishment of a rank correlation was not considered suitable. The data are summarized, however, in Table V.

TABLE V

RAIN-ROOM AND LABORATORY RESULTS ON SERIES II FABRICS

| Fabric Number | Rain-Room Penetration (Time in hrs.) | Drop Penetration (ml per 3 hrs.) | Hydrostatic Pressure (cm.) | Rain Tester Initial penetration(time in sec.) | Rain Tester (gm./ 20 min.) |
|---|---|---|---|---|---|
| 1 | 4.5 | 44 | 63 | 19 | .68 |
| 2 | 11.1 | 12 | 65 | 18 | .34 |
| 3 | 21.7 | 13 | 68 | 35 | .55 |
| 4 | 44.5 | 3 | 75 | 48 | .11 |
| 5 | 39.2 | 3 | 67 | 79 | .27 |
| 6 | 5.0 | 34 | 69 | 13 | .40 |
| 7 | 23.1 | 19 | 72 | 50 | .56 |
| 8 | 20.3 | 9 | 66 | 56 | .49 |
| 9 | 62.7 | 3 | 67 | 92 | .26 |
| 10 | 60.9 | 5 | 56 | 209 | .19 |
| 11 | 15.3 | 24 | 70 | 22 | .74 |
| 12 | 25.8 | 17 | 70 | 50 | .63 |
| 13 | 30.4 | 12 | 69 | 71 | .46 |
| 14 | 55.5 | 5 | 58 | 25 | .83 |
| 15 | 83.6 | 1 | 55 | 66 | .13 |
| 16 | 12.3 | 31 | 65 | 28 | .78 |
| 17 | 27.1 | 17 | 71 | 113 | .30 |
| 18 | 37.5 | 2 | 62 | 127 | .19 |
| 19 | 27.2 | 15 | 48 | 7 | 3.01 |
| 20 | 95.3 | 2 | 36 | 9 | 2.33 |
| 21 | 24.0 | 11 | 82 | 735 | .17 |
| 22 | 92.5 | 4 | 70 | 198 | .06 |
| 23 | 34.9 | 5 | 91 | 625 | .22 |
| 24 | 37.0 | 5 | 80 | 1017 | .08 |
| 25 | 98.1 | 2 | 66 | 756 | .07 |

A mathematical relationship to permit prediction of rain performance on the basis of data obtained with fabric specimens on holders (which correlate with garment performance) was established by calculating regression equations. A coefficient of correlation was used to express the closeness of the relationships. In addition to the regression equations and coefficients of correlation, the standard error of estimates

and 90% confidence limits shown in Table VI were also calculated to permit more valid interpretation of the data.[6]

The data shown in Tables IV and V have been plotted to show the relationships between the water resistance of the fabrics in Series I as measured in the rain-room and as determined by the drop-penetration (Figure 4), Bundesmann (Figure 5), duPont (two methods, Figures 6 and 7), and hydrostatic-pressure (Figure 8) tests. Data for both single and double layers of the fabrics are plotted in all the graphs except Figure 7, in which case the conditions of test precluded evaluation in double-layer form. Similar graphs have also been plotted for the Series II fabrics (single layers only) based on the results shown in Table V to demonstrate the relationships between rain-room data and the values obtained by the drop-penetration (Figure 9), duPont (Figure 10), and hydrostatic-pressure (Figure 11) tests.

The graphs showing the relationships between rain-room and laboratory tests on the fabrics in both Series I and Series II covered such a wide range (the best fabric often numerically exceeding the worst by a ratio of more than 1000 to 1) that it was found expedient to plot both laboratory and rain-room values logarithmically. When this was done, in most cases a straight line could be drawn reasonably close to the plotted points. The relationship between the results of a given laboratory test and the rain-room penetration time can be represented by the equation

$$\text{Log } Y = a + b \log X,$$

where Y and X represent rain-room and laboratory test values respectively. Because the hydrostatic test values for the seven fabrics in Series I were found to vary within a comparatively narrow range, they could be adequately plotted along the arithmetic scale of semi-logarithmic paper, plotting the rain-room data along the logarithmic scale. The equation derived in this case was

$$Y = a + b \log X.$$

Inspection of these graphs reveals that there is often a considerable discrepancy between the estimated and actual rain-room values. Thus, citing Figure 4 as an example, it can be seen that a single-layer fabric in Series I with a drop-penetration time of 8.3 minutes, has an estimated penetration time under a one-inch-per-hour rainfall of about 240 minutes, whereas the fabric actually lasted for 625 minutes. Many points which deviate similarly from the regression line can be noted in all of the graphs for both Series I and Series II.

The deviations of actual from estimated values are not in general attributable to lack of precision in the various laboratory test methods or in the rain-room, since in most cases each point on the graphs represents the average of a number of individual determinations which are in

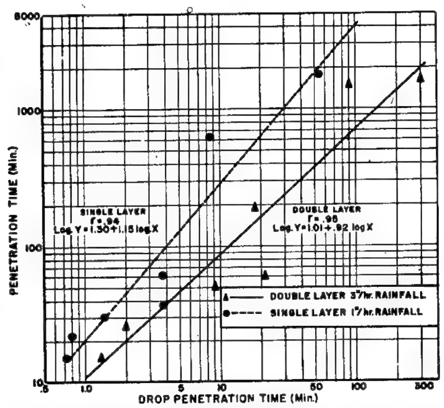

Fig.4-RELATIONSHIP BETWEEN PENETRATION TIME (RAIN ROOM) AND DROP PENETRATION FOR 7 SINGLE & DOUBLE LAYER FABRICS (SERIES I FABRICS)

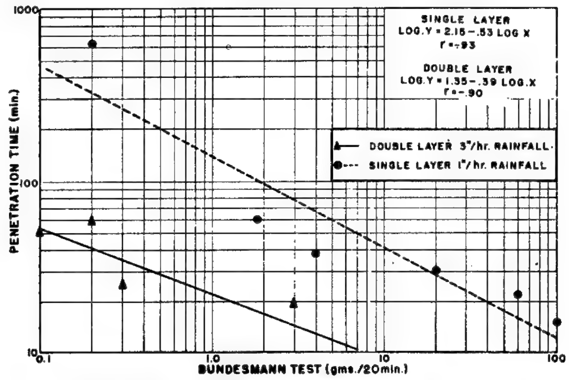

Fig.5- CORRELATION OF RAIN ROOM WITH BUNDESMANN TEST (Series I Fabrics)

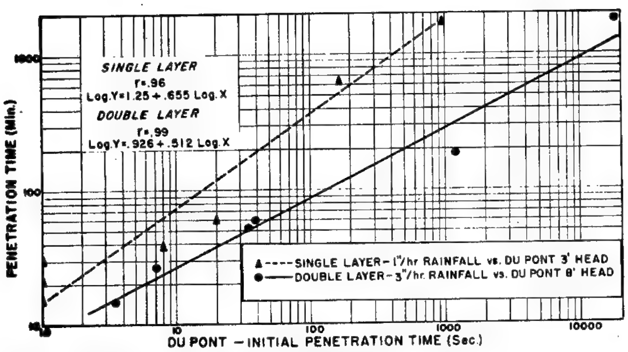

Fig.6-CORRELATION OF RAIN ROOM WITH DU PONT RAIN TESTER (SERIES I FABRICS)

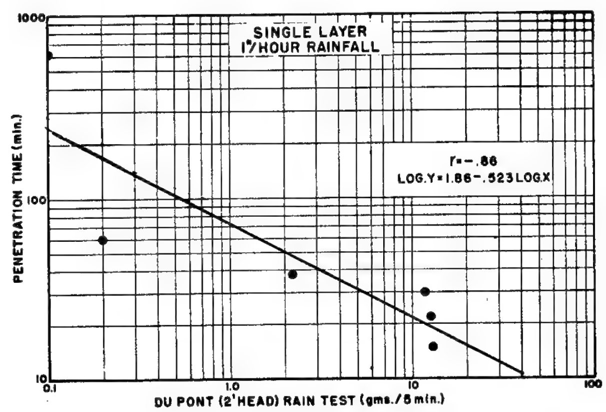

Fig.7-CORRELATION OF RAIN ROOM WITH DU PONT RAIN TESTER (SERIES I FABRICS)

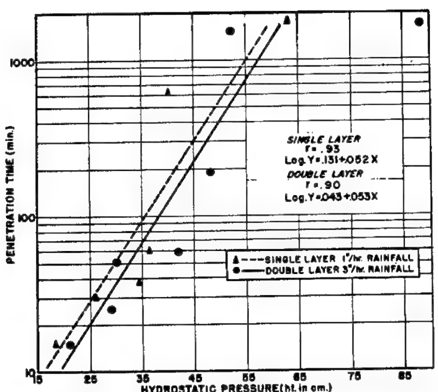

Fig.8-CORRELATION OF RAIN ROOM WITH HYDROSTATIC PRESSURE (SERIES I FABRICS)

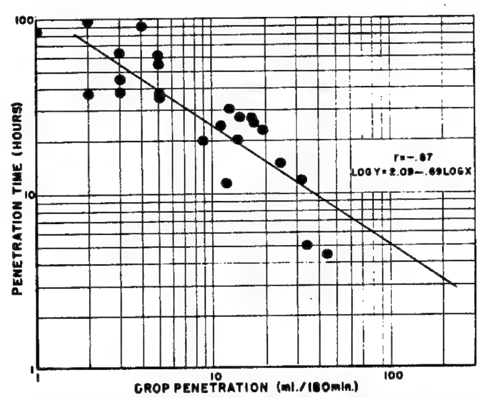

Fig.9-CORRELATION OF RAINROOM (3"/HOUR) WITH DROP PENETRATION FOR SINGLE LAYERS OF FABRIC (SERIES II)

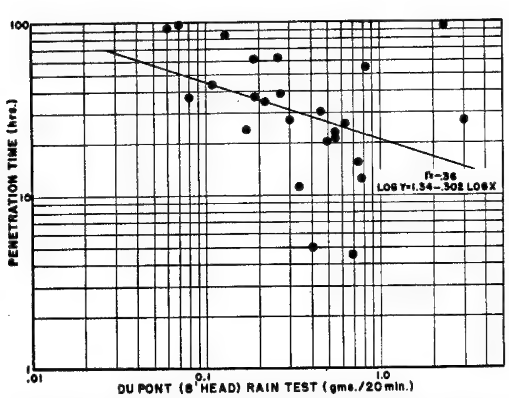

Fig.10-CORRELATION OF RAINROOM (3"/HOUR RAINFALL) WITH DU PONT RAIN TESTER FOR SINGLE LAYERS OF FABRIC (SERIES II)

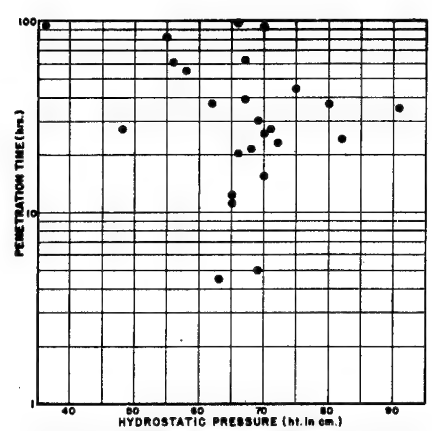

Fig.11-CORRELATION OF RAINROOM (3"/HOUR RAINFALL) WITH HYDROSTATIC PRESSURE FOR SINGLE LAYERS OF FABRIC. (SERIES II)

relatively good agreement among themselves. The deviations appear to arise from the fact that each test which was correlated with the rain room does not necessarily measure exactly the same characteristics as the rain room. Since the fabrics tested varied widely in type of weave, weight, yarn number, twist, etc., it can readily be seen that unless each of the laboratory tests is affected by these various characteristics in exactly the same way as the rain room, some discrepancies must be expected between actual and estimated values. For example, fabric thickness may have a much greater influence on rain-room than on drop-penetration test results because of the fact that the former is not an accelerated test and is less severe in its action than the latter. Thus many of the points on the charts are some distance from the regression line, indicating that the estimated rain-room values on the basis of laboratory test results are not exactly the same as the actual results.

For this reason each graph or estimating equation indicates, not the exact, but the most probable rain-room penetration time which would be obtained for a fabric of a given water resistance as measured by the laboratory test in question. Since this is the case, a standard error of estimate was calculated to permit prediction of the probability that the rain-room time will fall within a certain range of values.

To provide a margin of safety for estimating rain-room values the standard error of estimate was used to calculate the 90-percent confidence limits [6] for each test. These limits are expressed in Table VI in terms of percentages of the estimated Y or rain-room value. The confidence limits permit estimation of the range within which rain-room values could be expected to fall nine out of ten times on the basis of the laboratory test value. For example, a single-layer fabric with a drop-penetration value of 1.4 minutes resists penetration in the rain-room under a one-inch-per-hour rainfall for approximately 30 minutes according to Figure 4. Using the values for the 90-percent limits (lower limit 52 percent, upper limit 191 percent) it can be seen the rain-room value would be no less than 15.6 and no greater than 57.3 minutes nine times out of ten. In a like manner the time limits within which any specimen would be expected to resist penetration in the rain-room can be determined.

The information obtained by this correlation study can be put to practical use in establishing minimum standards for laboratory test values. For example, it is desired to ascertain whether fabrics which will eventually be made into garments will withstand a one-inch-per-hour rainfall for 100 minutes. According to Figure 4, the fabric whose most probable rain-room time is 100 minutes has a drop-penetration time of 4.0 minutes. However, the 90-percent confidence limits are such that a fabric with a drop-penetration time of 4.0 minutes could resist penetration in the rain room for as short a period of time as 52 minutes. Therefore the drop-penetration value must be set higher in order to

## TABLE VI

### STATISTICAL ANALYSIS OF CORRELATIONS OF LABORATORY AND RAIN-ROOM TEST RESULTS

| Test | Regression Equation<br>X - Laboratory Value<br>Y - Rain Room Value | Correlation Coefficient | Standard Error of Estimate (Log Value) | 90% Confidence Limits (Percent of Estimated Y Values) Lower | Upper |
|---|---|---|---|---|---|
| **SERIES I** | | | | | |
| **SINGLE LAYERS** | | | | | |
| Drop Penetration (min/10 ml) | Log Y = 1.30 + 1.15 log X | 0.94 | .28 | 52 | 192 |
| Hydrostatic (cm.) | Log Y = 0.131 + .052 X | 0.93 | .33 | 47 | 214 |
| duPont Rain Tester | | | | | |
| 3' head, initial penetration (sec.) | Log Y = 1.24 + 0.66 log X | 0.96 | .24 | 57 | 175 |
| 3' head, (sec./4 gm) | Log Y = 0.96 + 0.416 log X | 0.94 | .31 | 49 | 204 |
| 2' head. (gms/5 min.) | Log Y = 1.86-0.523 log X | -0.86 | .33 | 47 | 214 |
| Bundesmann (gm/20 min.) | Log Y = 2.15 - 0.53 log X | -0.93 | .24 | 57 | 175 |
| **DOUBLE LAYERS** | | | | | |
| Drop Penetration (min/10 ml.) | Log Y = 1.01 + 0.92 log X | 0.95 | .28 | 52 | 192 |
| Hydrostatic (cm.) | Log Y = 0.43 + .053 X | 0.90 | .34 | 46 | 218 |
| duPont Rain Tester | | | | | |
| 8' head, initial penetration (sec.) | Log Y = 0.93 + 0.512 log X | 0.99 | 0.13 | 74 | 135 |
| Bundesmann (gm/20 min.) | Log Y = 1.35 - 0.39 log X | -0.90 | 0.15 | 71 | 141 |
| **SERIES II** | | | | | |
| **SINGLE LAYERS** | | | | | |
| Drop Penetration (ml/3 hrs.) | Log Y = 2.09 - 0.69 log X | -0.87 | 0.18 | 66 | 150 |
| Hydrostatic (cm.) | (No Correlation) | --- | ---- | -- | --- |
| duPont Rain Tester | | | | | |
| 8' head, gms/20 min. | Log Y = 1.34 - 0.302 log X | -0.36 | 0.34 | 46 | 218 |
| 8' head, initial penetration (sec.) | Log Y = 0.981 + 0.271 log X | 0.44 | 0.33 | 47 | 214 |

provide a margin of safety. Since the desired minimum value is 100 minutes and the lower limit for the drop-penetration test in single layers is 52 percent (Table VI) it can be seen that by dividing 100 minutes by 52 percent a value of 192 minutes is obtained. This value is therefore the one whose lower confidence limit is 100 minutes. Using Figure 4 again it can be seen that a fabric with a rain-room penetration time of 192 minutes will have a drop-penetration time of approximately 75 minutes. This value is therefore chosen as the minimum drop-penetration value which will ensure with reasonable certainty a rain-room penetration time of at least 100 minutes. The same procedure can be applied to the other laboratory tests to obtain any desired minimum rain-room value.

Having shown how the laboratory penetration tests can be used to predict rain performance it became desirable to ascertain which of these gave the most reliable estimate of rain protection. The coefficients of correlation and standard errors of estimate obtained for the tests used to evaluate the single-layer fabrics in Series I were nearly the same. The closeness of these two statistical criteria indicates that, for all practical purposes, no one of these tests appears to predict the rain performance of garments better than another. However, in the evaluation of the double-layer fabrics in Series I the duPont rain test (8-ft. head) with a coefficient of correlation of 0.99 and a standard error of estimate of 0.13 appears to be more suitable than the other laboratory tests for predicting rain-room penetration time. The data obtained on this series of fabrics for the drop-penetration, hydrostatic and Bundesmann tests showed that no one of these tests was markedly superior to the others. The Bundesmann test, because of its low standard error of estimate, appears to be somewhat better than the others, but the small number of fabrics on which data could be obtained (four fabrics) did not permit this test to be classified as superior to the other two.

In a like manner the efficacy of the drop-penetration test, the hydrostatic-pressure test, and the two modifications of the duPont rain test, was determined, using the fabrics in Series II, which were evaluated in single layers under a three-inch-per-hour rainfall. The first modification of the duPont test consisted of weighing the amount of water which had penetrated the fabric in a 20-minute period. The second and more rapid method consisted of determining the time in seconds required for initial penetration (appearance of the first drop) to occur. The coefficients of correlation for the two values were -0.36 and 0.44 respectively, indicating only a slight degree of correlation between the rain test and the rain-room for this series of fabrics. In this series, as shown in Figure 11, no correlation was observed between the hydrostatic-pressure test and rain-room penetration time. The drop-penetration test, which had proved to be satisfactory in the evaluation of single and double layers in Series I also showed a high coefficient of

correlation of -0.87 and a low standard error of estimate of 0.18 for the Series II fabrics, indicating that this test should be suitable for estimating rain-room penetration time.

The analyses made to this point on the fabrics in Series I appear to show that the four penetration tests can be used interchangeably to estimate rain-room protection. However, such is not the case with hydrostatic-pressure test, in spite of the rather high coefficient of correlation and relatively low standard error of estimate. For example it can be seen in Figure 8 that a single-layer fabric with a hydrostatic-pressure value of 40 cm. gives an estimated rain-room penetration time of 160 minutes, and that a fabric with a hydrostatic-pressure value of 44 cm. gives an estimated rain-room value of 260 minutes. Therefore a ten-percent increase in the average hydrostatic pressure value corresponds to a 62.5 percent increase in rain-room penetration time. This percentage will increase at the higher hydrostatic values and decrease at the lower values. Since most good water-resistant fabrics have relatively high hydrostatic-pressure values, it can be seen that small percentage differences at these higher hydrostatic pressures will be reflected in large differences in rain-room penetration times. It can also be seen that it is entirely possible that several fabrics having nearly the same hydrostatic-pressure value could possess widely different protective values in the rain-room. The insensitivity of this laboratory test possibly explains the lack of correlation between hydrostatic-pressure and rain-room penetration time on the Series II fabrics (Figure 11).

The duPont and drop penetration values are more reliable indicators of rain-room protection time than hydrostatic results, because given percentage changes in the two former tests are reflected in more similar percentage changes in rain-room values. For example, in the drop-penetration test (Figure 4), a 10-percent increase from 20 to 22 minutes corresponds to a 12.5-percent increase in rain-room protection time, and a 20-percent drop-penetration increase from 20 to 24 minutes is the equivalent of an 18.7-percent rise in the rain-room value. In the case of the duPont rain tester (Figure 6), as the laboratory value increases 10 or 20 percent from 20 seconds to 22 or 24 seconds, the corresponding rain-room change is 5.9 or 11.1 percent.

Based on the analyses which have been performed it has been shown that the drop-penetration test is most suitable for predicting rain performance of a wide range of fabrics. The duPont rain test, although not as widely applicable as the drop penetration test, is most suitable for estimating the rain performance of either single or double-layer fabrics possessing the water-resistance characteristics desired by manufacturers producing civilian-type rain coats. The Bundesmann test appears to be almost as satisfactory as the rain tester, but its limited use and range preclude its general acceptance. The hydrostatic-pressure

test is not as suitable as the other penetration tests for predicting the rain performance of a wide range of fabrics. This may be due to its relative insensitivity to those characteristics which influence rain protection, such as thickness and density.

## IV. CONCLUSIONS

1. Data obtained using fabric holders correlates quite well with data obtained from garment wearing tests. Specimens tested on holders may be used in lieu of garments on human subjects to estimate the approximate protection afforded by fabrics under a specified rainfall.

2. The most probable rain room protection time of a fabric treated with a durable water repellent compound can be estimated from the results of laboratory penetration tests by use of the equations $\log Y = a + b \log X$ for the duPont, drop-penetration and Bundesmann tests, and $\log Y = a + bX$ for the hydrostatic test.

3. The drop-penetration, Bundesmann and duPont tests are equally reliable for estimating the rain-room penetration time of single and double layers of fabric which resist penetration under a one- and three-inch rain-fall, respectively, for a few minutes to approximately 24 hours with the rain room. The complexity of the Bundesmann apparatus and its relatively limited range precludes its general acceptance as a test instrument.

4. The hydrostatic-pressure test correlates well within this range of water resistance, but is apparently less sensitive to characteristics influencing rain protection than the other tests, and hence appears to be inherently less reliable.

5. For fabrics possessing a very high degree of water resistance (5 to 100 hours as single layers under a 3-inch per hour rainfall) the drop-penetration test appears to be the only method which can be used to estimate rain-room penetration. Within this range of water resistance the duPont rain test is a poor index of rain protection, and the hydrostatic test shows no correlation with the rain room.

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